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Reducing EMI in SiC Direct Torque Controlled Motor Drive

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Reducing EMI in SiC Direct Torque Controlled Motor Drive

An Undergraduate Honors Thesis
In the
Department of Electrical Engineering

by

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Statement of Originality

This is to certify that this submission is my own work, and to the best of my knowledge, it contains no materials previously published or written by another person, except where due acknowledgement is made in the paper. Any contribution made to the research by others is explicitly acknowledged in the paper. I also declare that the intellectual content of this paper is the product of my own work, and all other assistance received is acknowledged.

Michael Sykes

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Reducing EMI in SiC Direct Torque Controlled Motor Drive

By

Michael Sykes

Abstract

This paper covers the comparison between Silicon (Si) vs Silicon Carbide (SiC) for Motor Drive systems and a possible control algorithm to limit the increased Electromagnetic Interference (EMI) caused by using SiC transistors for the inverter. Motor Drive systems need constant improvements if the world is going to move on from machines that emit CO_2 and other harmful gases into the Earth's atmosphere. One reason these electric machines are not commonplace today is because of their efficiency and other problems they may cause. Silicon transistors are the most commonplace transistor around the world today, but advances over the past few decades have included newer technologies which rival Si transistors. This new technology proves to significantly improve the efficiency of the motor drive system but also has some other adverse effects such as EMI and cost that Si devices do not have. Thus, a comparison between them show the advantages and disadvantages to each for the overall system. If size and weight constraints do not matter then a SiC transistor would best serve a motor drive system in terms of efficiency and saving money in the long run. However, the system would cost more up front than a typical system with a Si transistor but would not be as efficient. A Direct Torque Controlled (DTC) motor drive with SiC transistors that effectively limits EMI and benefits from the SiC transistor is the end goal of this project, thus a contemplated control algorithm is considered in limiting the EMI produced and will be pursued in the future.

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Introduction

Silicon Carbide (SiC) transistors are becoming more common place in today's electronic world because of their benefits for certain applications. The advantages of SiC over Silicon (Si) are hard to ignore for certain applications. For instance, SiC can switch at much higher frequencies than Si, SiC has significantly reduced switching losses compared to a Si device, and SiC can withstand much higher temperatures than a Si device[1][2][3]. Since SiC is a relatively newer concept, as research develops, these devices will start to replace Si devices in most of their applications.

Motor drive systems need to be improved from what they are now to be viable options as replacements. Current systems emit harmful gasses in the atmosphere that is a leading cause in global warming[4]. Using SiC in motor drives are starting to become more popular options because of their advantages in efficiency, however, there is always trade-off, and these disadvantages must be considered while looking at the system.

This paper will briefly talk about motor drive systems and the control method selected for the motor drive that will be altered to reduce the Electromagnetic Interference (EMI) issues seen with SiC transistors. The control method will be reviewed to show why it was chosen and how the switches interact with the system as a whole. A comparison between Si and SiC will also take place to show their respective advantages and disadvantages to the system. Lastly, a proposed change to the switching algorithm will be recommended for future testing along with possible change to the hysteresis parameters to determine if a more efficient lookup table and/or hysteresis can sufficiently reduce the EMI emissions of a Direct Torque Controlled (DTC) motor drive system with SiC switches.

Motor Drive Systems

Motor drive systems are used extensively around the world for applications such as elevators, pumps, fans, and electric powered motors. These applications require precise control of the frequency, current, and voltage which in turn control the speed, torque, and direction. This precision is essential in the control of the system.

A DTC motor drive is a form of control known as the hysteresis or bang-bang controller. The reason its known as that type of controller is because part of its control scheme uses hysteresis controllers to abruptly switch between two values for the flux and torque of the motor drive. Based on the values of the phase voltages and phase currents, an estimated output of the flux and torque is calculated and then compared to reference values in their respective hysteresis controllers. A flux sector calculator also decides on a value and all three of these reference values are then sent into a look-up table that determines how to operate the switches. This output table is predefined within a system typically, thus when a change must occur in the system to keep the desired parameters within their limits, no time is wasted calculating the new parameters as it is a simple lookup table. The output flux and torque measured is then factored back into the hysteresis control as to maintain a variable control that can quickly adjust if the torque or flux exceed their error tolerance[5]. The system of control is depicted below in Figure 1. DTC was chosen as the control method for this motor drive because of the low losses experienced by them, as the switches will only switch to keep the torque and flux within their acceptable parameters. This limited amount of switching means less losses on the Metal Oxide Semiconductor Field Effect Transistors (MOSFETs), thus improving the efficiency of this control method. Other benefits of the DTC method are there are no major peaks in the current spectrum because of the random nature of the switching which helps in keeping the EMI low. Unfortunately, disadvantages to the DTC are high torque and flux ripples which relate to the average switching frequency of the drive and is what would be seen here if SiC inverter were utilized. To summarize, a DTC method for motor drives is useful for its simplicity, high-efficiency, and typically low EMI emissions[6].

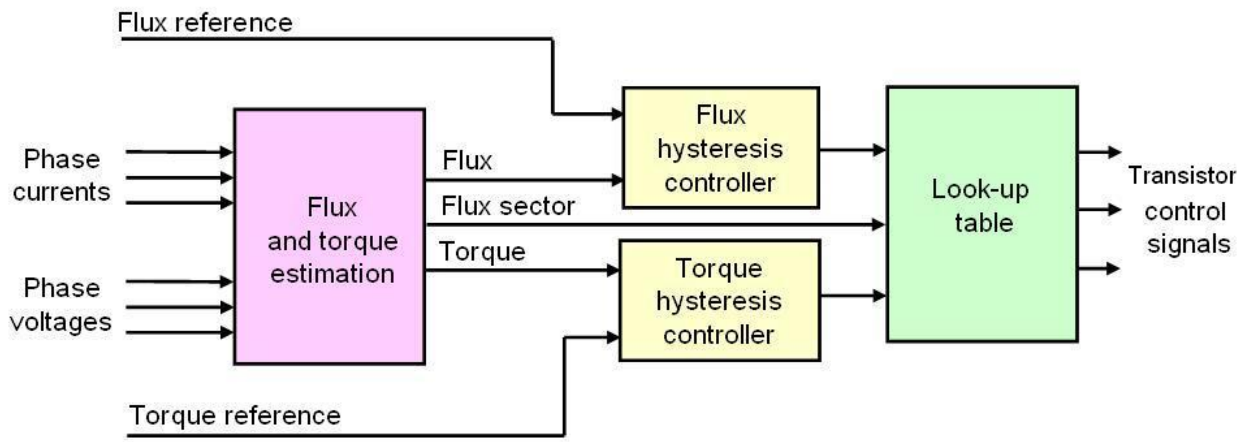

Figure 1: Operation of DTC Control Method [7]

Common switching circuits like a 3-phase inverter are used to control the motor. This type of circuit allows current to pass in multiple directions which means the motor can run forwards and backwards. This is essential for many applications, such as robots and vehicles. The amount of power received at the motor is determined by the transistor switches in the 3-phase inverter circuit and their efficiency. The power dissipated by the switch is power that will not make it to the motor, so according to the equation below,

$$P_{switch} = R_{switch} \times I^2$$

if the on resistance is low for the MOSFET/switch and it can switch fast, then more power can make it to the motor, and thus the motor is even more efficient. With the method proposed above, the circuit would only switch in order to maintain torque and flux levels inside their tolerance, which in turn reduces the losses seen at these switches. An example of a 3-phase inverter circuit is seen below in Figure 2. In this Figure, six switches can be identified that can alter the delivered current/voltage to the input of the motor drive, thus controlling the torque, speed, and direction.

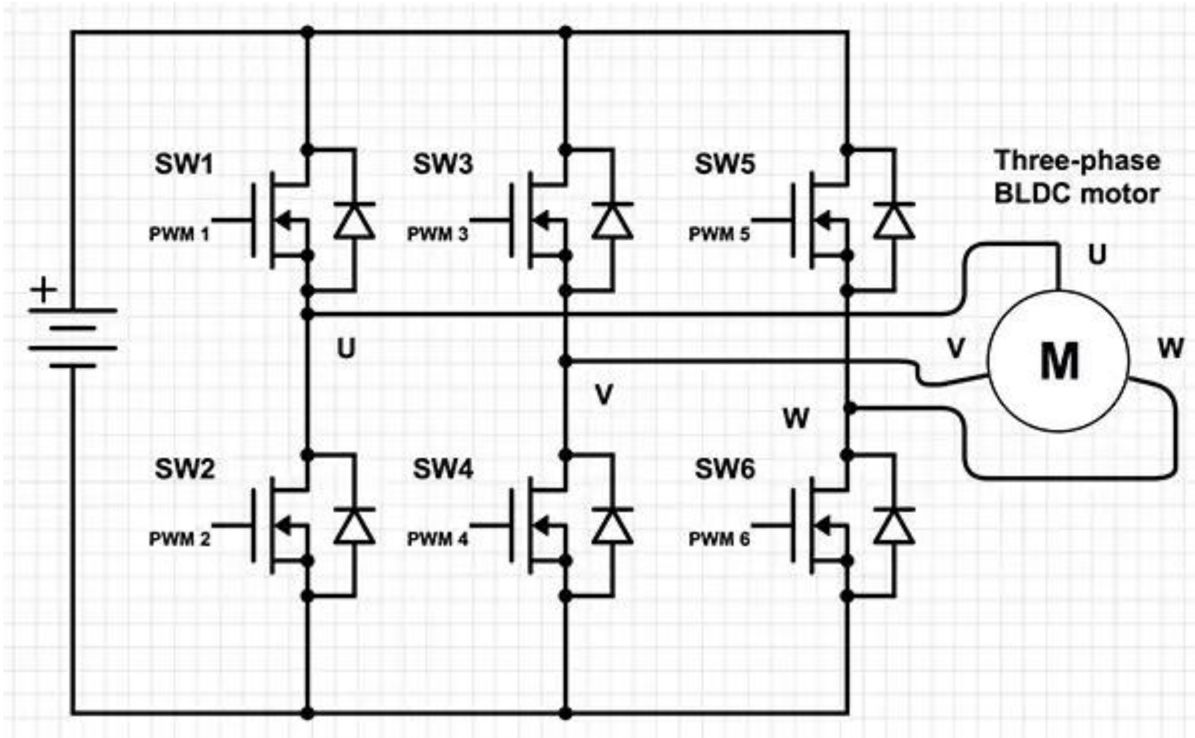

Figure 2: 3-Phase Inverter that Controls Motor [8]

As with most systems, a motor drive needs to be as efficient as possible with the energy it is using. From a economics standpoint, if the machine is saving energy and still emitting the same output, then the machine will save money over time. To accomplish these goals, more efficient parts are selected for the system. Common transistor switches found in motor drives today are made of Si and are relatively efficient for the system. However, as improvements are made to drive systems, losses in every part are considered to see what losses can be reduced. With the continued development of SiC transistors over the last two decades, they are starting to replace their predecessor, Si transistors, because of their reduced losses at a higher switching frequency. These new devices provide significant benefits to motor drive systems but can also cause some major disadvantages that will be explored in the next two sections.

Advantages of Silicon Carbide Transistors

Si has been around as the main player for transistors, but over the last few decades SiC has come into the picture as a better option for certain applications. These applications have to do with the characteristics of the SiC vs. Si. SiC has significant advantages over Si in terms of heat, power, and switching frequency. SiC can handle a much higher temperature than Si and therefore is better in applications where significant amounts of power is dissipated in the form of heat or in hotter environments. SiC also has 10x the electric field strength of Si according to the table below and can handle voltages at much higher levels than that of Si. SiC devices also have a low-on resistance that Si cannot match at the higher voltage levels, thus Si tends to have significantly higher losses than that of SiC in applications of high power and voltage. This makes SiC an ideal choice also for efficiency because a lower on-resistance, smaller dead time, and higher switching frequency will reduce the losses of the switch overall[9]. In the table, other attributes standout to why SiC is significantly better regarding the hole and electron mobility.

Properties	Si	4H-SiC	GaAs	GaN
Crystal Structure	Diamond	Hexagonal	Zincblende	Hexagonal
Energy Gap: E_G(eV)	1.12	3.26	1.43	3.5
Electron Mobility: μ_n(cm^2/V_S)	1400	900	8500	1250
Hole Mobility: μ_p(cm^2)	600	100	400	200
Breakdown Field: E_B(V/cm)X10^6	0.3	3	0.4	3
Thermal Conductivity(W/cm?)	1.5	4.9	0.5	1.3
Saturation Drift Velocity: v_s(cm/s)X10^7	1	2.7	2	2.7
Relative Dielectric Constant: e_S	11.8	9.7	12.8	9.5

Figure 3: Comparison of Various Properties of SiC vs Si [10]

Disadvantages of Silicon Carbide Transistors

Often when certain aspects get better something else in the system must suffer, this is referred to as trade-offs. When it comes to the comparison between SiC vs Si the trade-off is significant. According to Figure 3 below, the Wide-Band Gap (WBG) device, which includes SiC and Gallium Nitride (GaN) devices, has significantly less switching loss, but that steep change in the current and voltage when it switches also significantly increases the EMI. This can be very bad for any nearby electrical devices or the motor drive itself because the EMI can cause them not to operate correctly or even destroy electrical components in them. EMI is very dangerous because of its ability to destroy other electrical components, so the government has passed standards that EMI must fall under. All electrical systems must be able to pass Electromagnetic Compatibility (EMC) tests, otherwise these devices cannot be sold commercially because they can destroy any nearby electrical equipment. Thus, the electric motor drive system designed with better efficiency because of the SiC switches cannot be sold and is not profitable unless the EMI can be brought down. To reduce the EMI, something must be added to the design to reduce the waves emitted. Options to reduce EMI in a system include filters, shielding, and control modulation strategies. If filters or shielding are used they will add significant cost and size to the system while the last option may not reduce EMI enough. A combination of these options can supply some viable options. Based on the constraints of the motor drive system however, some of these options might not be plausible and efficiency may have to be lost to fit inside the constraints of the specific design.

Another disadvantage is the cost of SiC is much higher, but to offset the cost you get the benefits of SiC over its counterpart[11]. However, the issue of EMI still arises. If you want to reap the benefits of SiC, it must be running at the higher frequencies that Si cannot run at, so effective methods of reducing EMI must arise. If adding size and weight to the system does not factor into the conversation, then SiC is a much better choice over Si as the benefits of SiC will save money in the long run over a Si motor drive system.

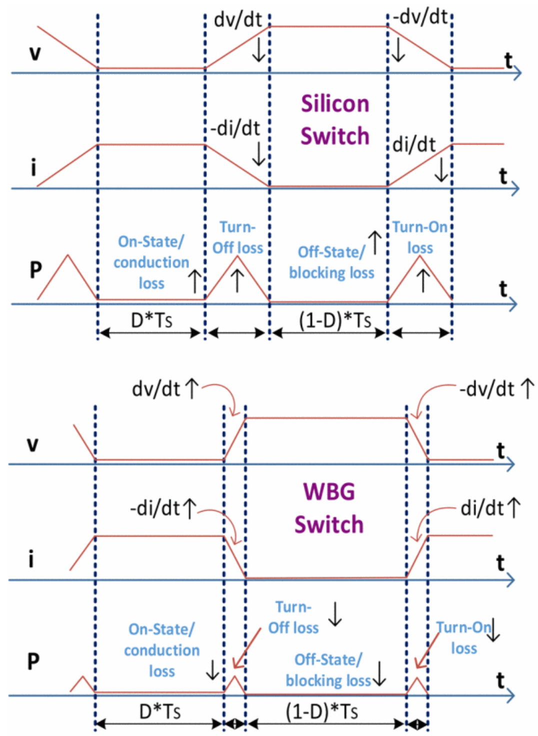

Figure 4: Comparison between WBG and Si Devices

Proposed Solution and Future Work

Further development of this project aims to find a solution in limiting EMI from a SiC inverter that is used to alter parameters of a DTC motor drive without adding complexity, weight, and cost to the system. Based on the motor drives control method, altering the lookup table to reduce torque ripple could possibly be a solution in reducing the EMI coming off the SiC switches[12][13] or using a Space Vector Modulation (SVM) approach in the DTC could also effectively reduce the EMI but would make the motor drive have a set frequency[14]. Another possible solution would be lowering the threshold change in the hysteresis so when the circuit does switch it is not having to compensate for as big of an error[15]. However, a downside to altering the hysteresis level is that it could cause the inverter to switch more, which in turn would increase the losses. Finding a so called “sweet spot” in-between would possibly be the best course of action along with coupling a small change in the lookup table to effectively reduce the EMI produced from the system without causing more losses than just using a Si inverter.

Testing this strategy will require a baseline test with a SiC inverter, the conventional lookup table, and set hysteresis parameters already defined by the previous graduate student who built the motor drive. Then a comparison should be made between the baseline and the altered lookup table to see if EMI emissions were lowered. Once confirmed the altered lookup table is correctly reducing the EMI emissions, a table comparison can be made between the efficiency of the system and the EMI emissions while the hysteresis is periodically changed to hopefully show a “sweet-spot” where the losses and EMI emissions are both at an acceptable rate but lowered.

Further development in this project would have been possible if Covid-19 did not severely limit the testing and resources needed, but there are high hopes in the fall for continuing this testing and possibly finding a solution that effectively reduces the EMI in this system without adding any cost, weight, or size.

Conclusion

Motor drive systems are important in today’s world as society is starting to move away from machines that emit CO_2. Many of these new machines are powered by electricity and are constantly being improved upon to become the better option over their counterparts. One key improvement to these electric machines are using SiC for the switches. These SiC switches are better than their Si counterparts for numerous reasons. They have significantly lower on resistance, can switch at higher frequencies, and suffer less in terms of switching losses. However, SiC does have certain disadvantages that must be addressed before being able to be fully implemented in motor drive systems. They suffer from EMI that must be reduced otherwise these machines cannot be sold commercially. If a solution is possible for the application then SiC is the obvious choice over Si, but in certain applications more losses may be better for certain systems if other constraints exist for the motor drive. Overall, SiC is a better choice for a motor drive system because of the efficiency of the switches if the added filters and control are taken to limit the EMI emitted from the system. One such way I propose of doing so is altering the lookup table and adjusting the hysteresis threshold to further reduce the EMI which will hopefully bring the EMI down to acceptable levels. This theory will hopefully be tested in the upcoming semesters.

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